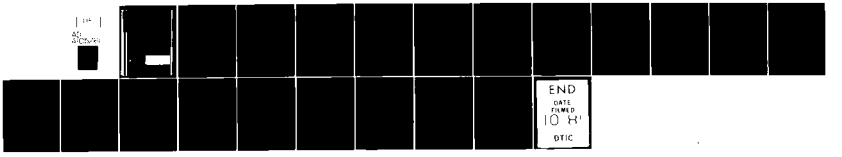
AD-A105 261 DEFENCE RESEARCH ESTABLISHMENT VALCARTIER (QUEBEC) F/G 20/5
LONG-TERM OPERATION OF A SEALED WAVEGUIDE CO 2 LASER,(U)
APR 81 P PACE, J CURICKSHANK
UNCLASSIFIED DREV-R-4207/81 NL



END
DATE FILMED
10 81
DTIC

CRDV RAPPORT 4207/81
DOSSIER 3633H-004
AVRIL 1981

DREV REPORT 4207/81
FILE 3633H-004
APRIL 1981

LONG-TERM OPERATION OF A SEALED WAVEGUIDE CO_2 LASER

P. Pace

J. Cruickshank

Centre de Recherches pour la Défense
Defence Research Establishment
Valcartier, Québec

BUREAU - RECHERCHE ET DEVELOPPEMENT
MINISTERE DE LA DEFENSE NATIONALE
CANADA

NON CLASSIFIÉ
DIFFUSION ILLIMITÉE

RESEARCH AND DEVELOPMENT BRANCH
DEPARTMENT OF NATIONAL DEFENCE
CANADA

CRDV R-4207/81
DOSSIER: 3633H-004

UNCLASSIFIED

DREV R-4207/81
FILE: 3633H-004

LONG-TERM OPERATION OF A SEALED WAVEGUIDE CO_2 LASER

by

P. Pace and J. Cruickshank

CENTRE DE RECHERCHES POUR LA DEFENSE
DEFENCE RESEARCH ESTABLISHMENT
VALCARTIER
Tel: (418) 844-4271

Québec, Canada

April/avril 1981

NON CLASSIFIE

RESUME

Nous avons utilisé un spectrographe de masse pour étudier la composition gazeuse lors du fonctionnement d'un laser CO_2 à guide d'ondes BeO. Les résultats de cette étude nous ont permis de construire des lasers à guide d'ondes scellés d'une durée utile supérieure à 7000 h. (NC)

ABSTRACT

A mass spectrometer has been utilized to study the gas composition during operation of a CO_2 laser using a BeO waveguide. The results of this study have allowed us to construct sealed waveguide lasers with predicted lifetimes in excess of 7000 h. (U)

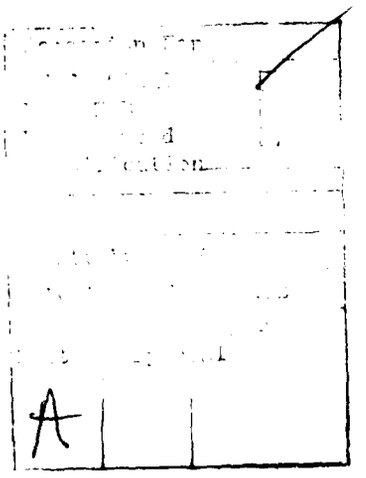


TABLE OF CONTENTS

1.0 INTRODUCTION

During the past few years, waveguide CO_2 lasers have received much attention as compact sources of tunable IR radiation; their characteristics have been reported by several authors (see Ref. 1 for a review). To exploit the compactness and the tunability of these lasers, it would be desirable to operate them in a sealed configuration; this would eliminate the additional equipment needed for gas circulation and it would avoid turbulence and fluctuating pressures which may cause frequency instabilities. For the specific application of interest (Ref. 2), an optical radar using heterodyne detection, a suitably designed, high-pressure, oversized waveguide (Ref. 3) may be used as a local oscillator. A laser of this type would have applications in laser communication systems and also as a wide-band tunable oscillator for IR spectroscopy.

In this report, we describe the design, the construction and the sealing techniques employed in the development of a BeO waveguide CO_2 laser that can be used as a local oscillator in an optical radar system with heterodyne detection. Emphasis has been placed both on ruggedizing the laser to enable its operation in a non-laboratory environment and on obtaining long-term sealed operation. Although there have been previous reports on sealed BeO waveguide lasers (Ref. 4), we were unable, until recently, to prolong their consistent lifetimes over a few hundred hours (Ref. 5).

This work was performed at DREV between November 1979 and December 1980, under PCN 33H04, Miniaturization of Lasers.

2.0 DESIGN AND CONSTRUCTION

The tube used for the construction of the laser was fabricated from a 99.5% pure beryllium oxide ceramic rod, 2.5 cm in diameter, and 12.5 cm long, with a drilled axial bore of 2 mm (Consolidated Ceramics, Van Sychels Road West, Hampton, N.J. 08827). This material was chosen because of its high thermal conductivity and good optical constants (Refs. 6, 7, and 8). Four side holes were drilled radially into the bore to accept the electrodes (Fig. 1); two of them were about 1 cm from the ends of the tube, the others were 1 cm apart and placed symmetrically about the tube centre. This provided a pair of excitation discharges electrically in parallel. Each pair was equipped with a 2-MΩ ballast resistor sufficient to eliminate any discharge instabilities.

The 90% Pt - 10% Rh cathodes were epoxied in the centre holes to minimize sputtering damage to the end mirrors. One of the stainless steel anodes was drilled to serve as a gas inlet, then connected to a 300-cm^3 stainless steel gas reservoir via an isolating Pyrex tube. In this configuration, both discharges can be operated reliably if the electric field in the intercathode spacing never exceeds the one between the cathode and its corresponding anode. This can be achieved by placing the cathodes sufficiently far from each other (Ref. 9). However, in our configuration, this would have meant inefficient use of the discharge volume; we thus chose to place the ballast resistors on the anode ends of the tube. We could have used a three-electrode tube, but the only ones readily available had four holes. The following experiments were thus conducted by joining the centre two electrodes and connecting them directly to the negative high voltage source, while the anodes were grounded through the 2-MΩ resistors. High voltage hazards were controlled by appropriate shields.

Among the various types of hollow-waveguide-laser resonators available (Refs. 10-14) that lead to low-loss situations favouring the EH_{11} mode, we chose to use the convenient configuration of flat reflectors placed close to the ends of the guide. The 96% reflectivity ZnSe output coupler was epoxied directly on one end of the tube whereas a 99.7% transmitting ZnSe window sealed the other end. This allowed the use of either a flat mirror, or grating, as the other cavity element. In this configuration the losses are a function of the distance between the end of the tube and the mirror (or grating) (Ref. 13). In this case the second cavity element was mounted on a piezoelectric translator positioned with an angular orientation device. The spacing between the sealing window and the mirror (or grating) could then be reduced to < 5 mm, which gives a loss of less than 0.4% (Ref. 14) at the mirror tube interface.

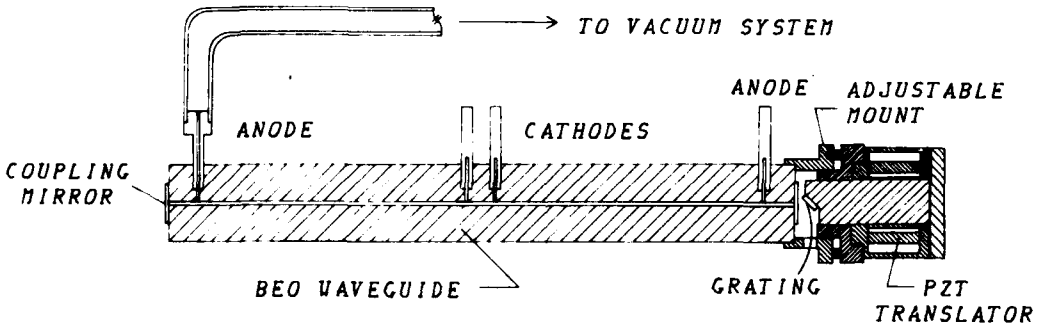


FIGURE 1 - Diagram of a Sealed CO_2 Waveguide Laser

The BeO laser tube and the ballast resistors were mounted in close contact with a water-cooled aluminum heat sink. Since this laser is to be used as a stable local oscillator in a heterodyne detection system, a Stark cell is also mounted on the aluminum structure. This aspect of the waveguide laser has been studied previously (Ref. 15) and will not be discussed in this report.

3.0 EXPERIMENTAL PROCEDURE

Figure 2 shows schematically the experimental arrangement. The laser and reservoir were connected through a valve to a gas mixing manifold. High-purity research grade gases were used and mixing was monitored using a capacitance manometer. The laser was also connected via a leak valve to a small mass spectrometer capable of mass number identification from 2 amu to 100 amu, with a resolution of $M/\Delta M = 50$ (M = mass number; ΔM = peak width at half-peak height).

The entire vacuum system was constructed of stainless steel; it was evacuated and heated to give a pressure better than about 5×10^{-8} torr before starting the experiments. During the experiments the gas was mixed in the manifold and the valve to the laser was closed. The mixture was then allowed to enter the laser, the pressure was adjusted, and the manifold was subsequently isolated from the system. At the desired time intervals, the sample gas was admitted to the ionization chamber of the mass spectrometer via the leak valve. Because of the small conductance of the leak valve and the 300-cm^3 reservoir, no significant changes of pressure could be detected in the laser, even after several samples had been removed. To minimize the measurement errors, the pattern coefficients and sensitivities of all the standard gases expected to exist in the laser were established before each experiment.

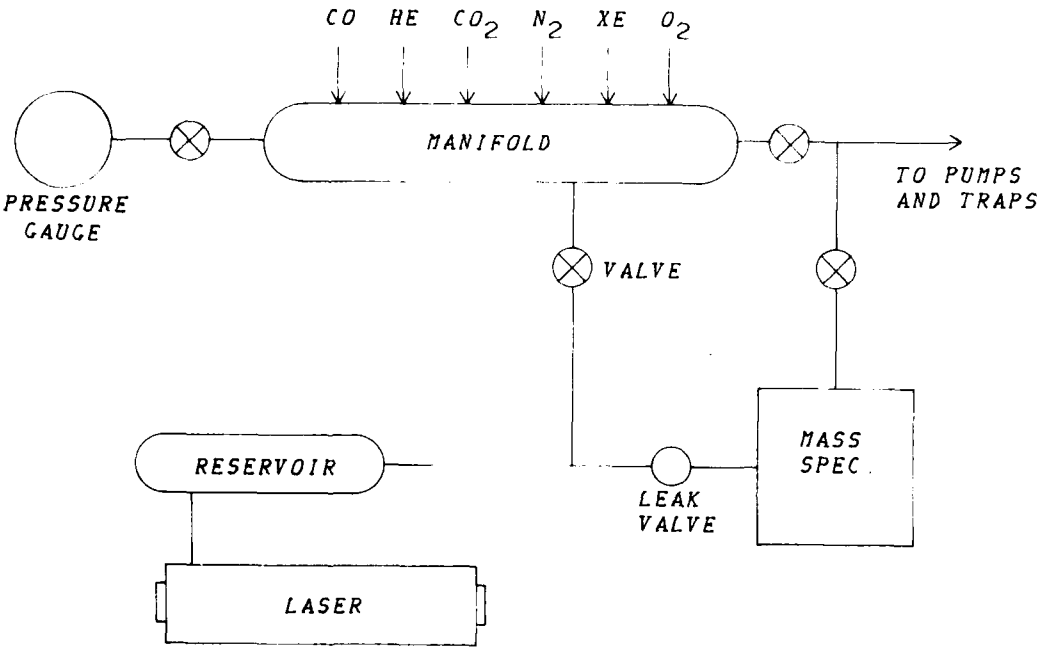


FIGURE 2 - Schematic diagram of the experimental apparatus

To oxidize the electrodes and any organic impurities we ran an electrical discharge with a small quantity of O_2 in the laser over a 24-h period (Refs. 4 and 16), after which the laser was pumped and the lasing gas mixture was admitted.

4.0 RESULTS

To facilitate the interpretation of the mass spectra, the initial experiments were conducted using gas mixtures containing only He and CO_2 in the ratio 56 torr He: 24 torr CO_2. The laser was operated at a total current of 4.6 mA and at a supply voltage of 8-9 kV. During the first few hours of operation the partial pressure of CO_2 fell by about 50% while the concentrations of both CO and O_2 increased following the relation:

$$CO_2 \rightleftarrows CO + \tfrac{1}{2} O_2 \qquad [1]$$

The output power gradually increased during this period. This is probably because of the more efficient excitation of the 00°1 level of the CO_2 caused by a collisional energy transfer from excited CO (Ref. 17). However, during the next 50 to 100 h, the output power declined to almost zero. Only in a couple of cases were we able to achieve 500 h of operation.

During the laser operation, the gas composition was sampled and analyzed every few hours; after the first few hours, there was very little change in the composition. Even after the laser had ceased to operate, ample amounts of CO_2, CO and O_2 still remained. In fact, if the laser was evacuated immediately after a test and filled with a gas mixture containing the same proportions of CO_2, CO and O_2 as the test that just terminated, lasing occurred at an output level similar to the original one. This pattern of events was repeated several times with different gas mixtures and the outcome was always similar. These results indicated that the decomposition of the CO_2 is not the majour problem and led us to look for other impurities adversely affecting laser action.

Considerable testing showed that the only detectable impurity that changed was the amount of water vapour in the laser. The plot of the relative concentration of water vapour and laser power against time (Fig. 3) indicates that there is a direct correlation between the increase in water vapour concentration and the decrease in laser power. To eliminate this, the laser was pumped and heated for several days; however, the same phenomena continued to occur. Finally, it was decided to place a 3A molecular sieve in the gas reservoir to control the partial pressure of water vapour. The results of the first test using the molecular sieve indicated that the partial pressure of the water vapour remained constant for the duration of the test: 1000 h. The output power increased a few percent during this time; however, the concentrations of CO_2 and O_2 declined while that of CO increased. This indicated that during the longer term operation, O_2 was being slowly removed from the discharge. According to eq. 1, this would cause more CO_2 to be decomposed in order to maintain an equilibrium, with the corresponding increase in CO concentration. In an attempt to delay this process, a few percent of O_2 were added to the initial gas mixture. The results of this test are shown in Fig. 4. It is again seen that the O_2 concentration slowly decreases while there is a corresponding increase in CO and decrease in CO_2. Nevertheless, the laser output power continued to increase over the duration of this test, a total of 2100 h.

The concentration curves in Fig. 4 have been linearly extrapolated to determine the concentrations at times beyond 2100 h which allows the prediction of the useful lifetime of this laser. These predicted gas compositions were then admitted to the laser and the output power was measured for several of them. The results are shown in Fig. 5. The power continues to increase for about 4500 h, and

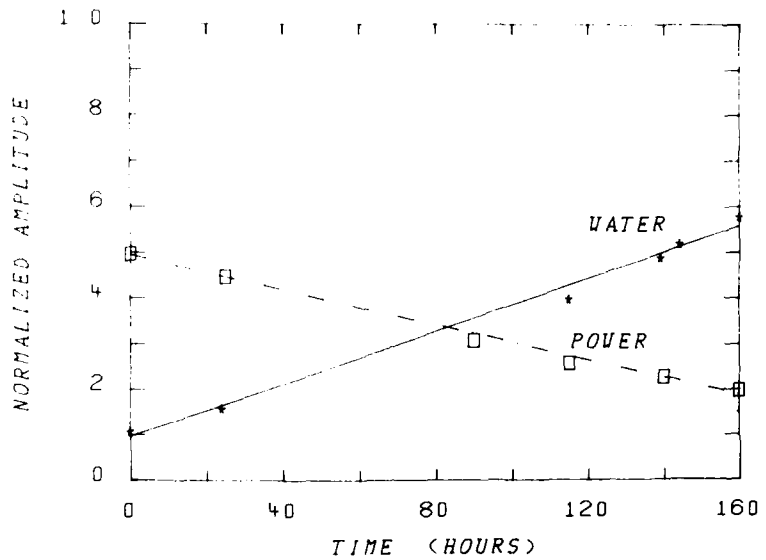


FIGURE 3 - Relative water vapour concentration and relative output power plotted against operating time

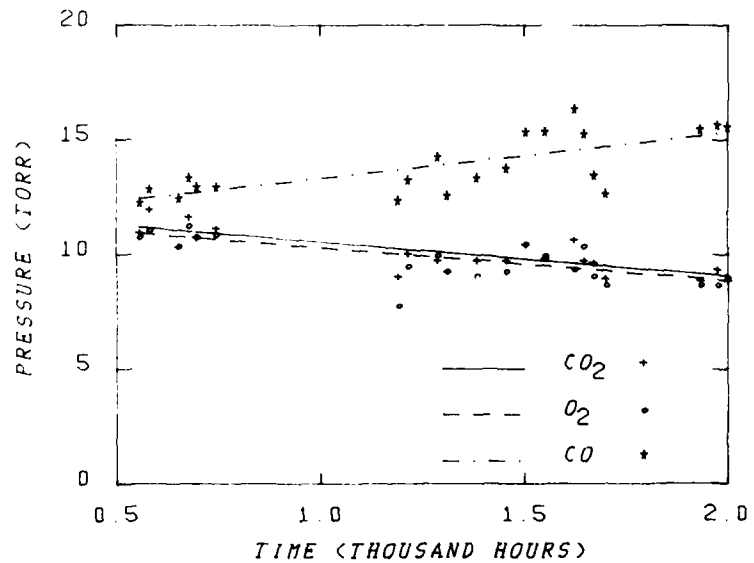


FIGURE 4 - Partial pressure of CO_2, O_2 and CO vs time using the 3A molecular sieve. Initial gas mixture: 56 torr He: 24 torr CO_2: 5 torr O_2

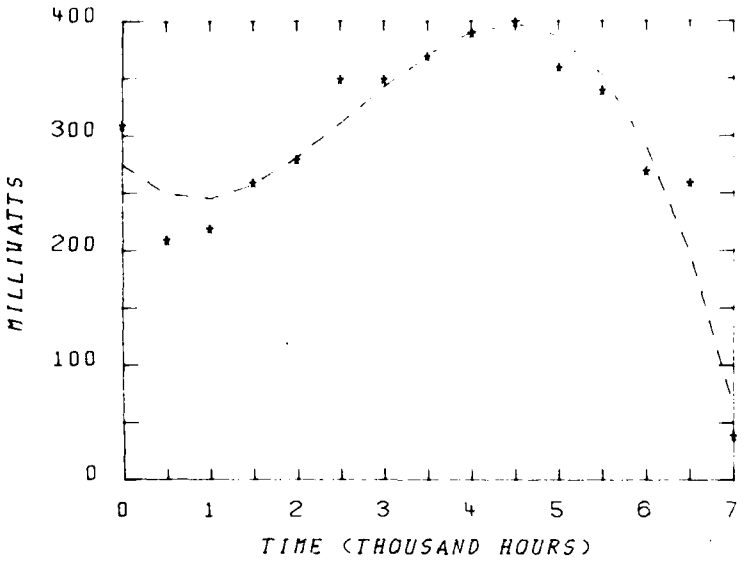


FIGURE 5 - Estimated output power vs time. Graph indicates extrapolated power based on data from Fig. 4.

then steadily declines; lasing terminates at 7000 h. It appears that even though the CO_2 concentration declines, the additional CO concentration contributes to increased output power and increased lasing efficiency. Nevertheless, the continuing loss of CO_2 eventually leads to termination of laser action.

The above results show that the laser lifetime is limited by the gradual loss of O_2. This could be caused by slow oxidation of the structural materials or possibly by absorption of the O_2 by the molecular sieve. To verify the latter assumption, we replaced the molecular sieve with P_2O_5. Although the test was performed only over 700 h, the results indicated that the concentrations remain

constant after the first 100 h and that after a slight initial decline, the output power remains stable over the same period. Since the concentrations of the various gases remained constant over the duration of the test, it was impossible to predict the operating lifetime of this device.

To simplify the construction and preparation of the laser tubes, we assembled lasers in which the windows and mirrors were sealed to the BeO tube via O-rings. A stainless steel collar was epoxied directly to the tube and the window was clamped against this collar using an O-ring as a vacuum seal. We also eliminated the high-vacuum system. The preparation then consisted in pumping with a roughing pump and then filling the lasers with a premixed gas. We also used gas mixtures containing N_2 and Xe and, in all cases, the results were similar. For example, with a mixture containing: $He:N_2:CO_2:Xe:O_2$, in ratios 54:19:19:06:03, we obtained over 5000 h of sealed operation. During this time the output power remained constant (following an initial decline). The test is continuing to determine the ultimate lifetime. Operation without the reservoir is also being investigated. Preliminary results are favourable and indicate that sealed operation in this configuration is possible.

5.0 DISCUSSION

The experiments indicate that water vapour is detrimental to the operation of this type of waveguide laser. We noticed that even in well prepared and clean laser tubes it was impossible to eliminate the outgassing of water vapour. At the present time we are not certain as to the effects of water in the system. It appears that the absorption coefficient of the water vapour continuum (Ref. 18) is too small at the partial pressures of interest to have any significant effect on the laser gain. On the other hand, as suggested by Peters (Ref. 19), hydrogen may have an adverse effect on laser action for it is relatively effective in quenching the 00°1 level of CO_2 (Ref. 20). It is thus possible that the water vapour concentrations measured in this experiment (± 0.1 - 0.5%) could provide sufficient hydrogen to reduce the gain enough to inhibit laser action. This conclusion seems to be contrary to those reached in other reports on sealed CO_2 laser systems (Ref. 19) wherein water has been added to increase sealed lifetimes. However, this latter approach has been successful only in conventional CW CO_2 and TEA laser devices, where water assists in the reformation of CO_2 from the discharge products and thus limits its decomposition.

To verify our assumptions, we injected a small quantity of water vapour into a normally operating waveguide laser: laser action ceased immediately. Although this indicates the adverse effects of water, it does not reveal the exact mechanisms involved in the quenching of the laser. The experiments presently in progress will hopefully clarify the situation.

It should also be noted that the lasers were not tested for "shelf-life" duration. To have "shelf-lives" of several years it might be necessary to eliminate the "O"-rings and epoxy seals in favour of hard-sealing techniques. This aspect of the sealed CO_2 waveguide laser is also under development.

6.0 CONCLUSIONS

From the preliminary experiments performed, it appears that water has a detrimental effect on the operation of waveguide lasers. In particular, we found that it is impossible to eliminate water vapour from BeO ceramic waveguide lasers by simply pumping and baking the system before admitting the laser gases. However, with the addition of a dessicant such as P_2O_5, we were able to control the partial pressure of water vapour and in so doing, we obtained laser lifetimes of several thousand hours. Experiments are underway to determine the origin and the effects of water vapour in the laser system.

7.0 ACKNOWLEDGEMENTS

The authors thank Messrs. J. Lemay and M. Lacombe for their expert technical assistance. Gratitude is also expressed to Dr. P. Lavigne who initiated the design and construction of the BeO waveguide lasers used in this study.

8.0 REFERENCES

1. Degnan, J.J., "The Waveguide Laser: A Review", Appl. Phys., Vol. 11, pp. 1-13, 1976.

2. Cruickshank, J.M., "Pulsed TEA-CO_2 Laser Radar with Heterodyne Detection", DREV R-4116/78, August 1978, UNCLASSIFIED

3. Jensen, R.E. and Tobin, M.S., "CO_2 Waveguide Laser", Appl. Phys. Lett., Vol. 20, pp. 508-510, 1972.

4. Laughman, L.M., "Long-Term Operation of a Sealed Waveguide CO_2 Laser", Rev. Sci. Inst., Vol. 47, pp. 1411-1413, November 1976.

5. Lavigne, P., Otis, G. and Vincent, D., "Performance Characteristics of a CO_2 Waveguide Laser", DREV R-4150/79, August 1979, UNCLASSIFIED

6. Abrams, R.L. and Bridges, W.B., "Characteristics of Sealed-Off Waveguide CO_2 Lasers", IEEE. J.Q.E., Vol. QE-9, pp. 940-946, 1973.

7. Burkhardt, E.G., Bridges, W.B. and Smith, P.W., "BeO Capillary CO_2 Waveguide Laser", Opt. Commun., Vol. 6, pp. 193-195, 1972.

8. Hall, D.R., Jenkins, R.M., Gorton, E.K. and Cross, P.H., "A Compact Sealed Waveguide CO_2 Laser", J. Phys. D: Appl. Phys., Vol. 10, pp. 1-6, 1977.

9. Hall, D.R., Jenkins, R.M. and Gorton, E.K., "A Frequency-Stabilized CW Waveguide Carbon Dioxide Laser", J. Phys. D: Appl. Phys., Vol. 11, pp. 859-869, 1978.

10. Degnan, J.J. and Hall, D.R., "Limited Aperture Waveguide Laser Resonator", IEEE. J.Q.E., Vol. QE-9, pp. 901-910, 1973.

11. Chester, A.M. and Abrams, R.L., "Mode Losses in Hollow Waveguide Lasers", Appl. Phys. Lett., Vol. 21, pp. 576-578, 1972.

12. Hall, D.R., Gorton, E.K. and Jenkins, R.M., "10 μm Propagation Lasers in Hollow Dielectric Waveguides", J. Appl. Phys., Vol. 48, pp. 1212-1216, 1977.

13. Abrams, R.L., "Coupling Losses in Hollow Waveguide Laser Resonators", IEEE. J.Q.E., Vol. QE-8, pp. 834-843, 1972.

14. Abrams, R.L. and Chester, A.N., "Resonator Theory for Hollow Waveguide Lasers", Appl. Opt., Vol. 13, pp. 2117-2125, 1974.

15. Lavigne, P., Deslauriers, A. and Lemay, J., "A Stark Cell for Frequency Control of a Waveguide CO_2 Laser", DREV R-4188/80, UNCLASSIFIED

16. Hochuli, U.E. and Sciacca, T.P., "Cold Cathodes for Sealed-Off CO_2 Lasers", IEEE. J.Q.E., QE-10, pp. 239-244, 1974.

17. Vargin, A.N., Gogokhiya, V.V., Konyakhow, V.K. and Pasynkova, L.M., "Rates of Resonant Vibrational Exchange Between the CO_2 Molecule and N_2 and CO Molecules", Sov. J. Quant. Electron., Vol. 6, pp. 119-121, 1976.

18. Kelly, P.L., McClatchey, R.A., Long, R.K. and Snelson, A., "Molecular Absorption of Infrared Laser Radiation in the Natural Atmosphere", Optical and Quantum Electronics, Vol. 8, pp. 117-144, 1976.

19. Peters, P.J.M., Witteman, W.J. and Zuidema, R.J., "Efficient Simple Sealed-Off CO Laser at Room Temperature", Appl. Phys. Lett., Vol. 37(2), pp. 119-121, 1980.

20. Strikcer, J., "Deactivation of CO_2 (010) and CO_2 (001) by Hydrogen and Deuterium", J. Chem. Phys., Vol. 64, pp. 1261-1265, 1966.

DREV R-4207/81 (UNCLASSIFIED)

Research and Development Branch, DND, Canada.
DREV, P.O. Box 8800, Courcelette, Que. GOA 1RO

"Long-Term Operation of a Sealed Waveguide CO_2 Laser"
by P. Pace and J. Cruickshank

A mass spectrometer has been utilized to study the gas composition during operation of a CO_2 laser using a BeO waveguide. The results of this study have allowed us to construct sealed waveguide lasers with predicted lifetimes in excess of 7000 h. (U)

DREV R-4207/81 (UNCLASSIFIED)

Research and Development Branch, DND, Canada.
DREV, P.O. Box 8800, Courcelette, Que. GOA 1RO

"Long-Term Operation of a Sealed Waveguide CO_2 Laser"
by P. Pace and J. Cruickshank

A mass spectrometer has been utilized to study the gas composition during operation of a CO_2 laser using a BeO waveguide. The results of this study have allowed us to construct sealed waveguide lasers with predicted lifetimes in excess of 7000 h. (U)

DREV R-4207/81 (UNCLASSIFIED)

Research and Development Branch, DND, Canada.
DREV, P.O. Box 8800, Courcelette, Que. GOA 1RO

"Long-Term Operation of a Sealed Waveguide CO_2 Laser"
by P. Pace and J. Cruickshank

A mass spectrometer has been utilized to study the gas composition during operation of a CO_2 laser using a BeO waveguide. The results of this study have allowed us to construct sealed waveguide lasers with predicted lifetimes in excess of 7000 h. (U)

DREV R-4207/81 (UNCLASSIFIED)

Research and Development Branch, DND, Canada.
DREV, P.O. Box 8800, Courcelette, Que. GOA 1RO

"Long-Term Operation of a Sealed Waveguide CO_2 Laser"
by P. Pace and J. Cruickshank

A mass spectrometer has been utilized to study the gas composition during operation of a CO_2 laser using a BeO waveguide. The results of this study have allowed us to construct sealed waveguide lasers with predicted lifetimes in excess of 7000 h. (U)

CRDV R-4207/81 (NON CLASSIFIE)

Bureau - Recherche et Développement, MDN, Canada.
CRDV, C.P. 8800, Courcelette, Qué. GOA 1RO

"Fonctionnement à long terme d'un laser CO_2 à guide d'ondes scellé"
par P. Pace et J. Cruickshank

Nous avons utilisé un spectrographe de masse pour étudier la composition gazeuse lors du fonctionnement d'un laser CO_2 à guide d'ondes BeO. Les résultats de cette étude nous ont permis de construire des lasers à guide d'ondes scellés d'une durée utile supérieure à 7000 h. (NC)

CRDV R-4207/81 (NON CLASSIFIE)

Bureau - Recherche et Développement, MDN, Canada.
CRDV, C.P. 8800, Courcelette, Qué. GOA 1RO

"Fonctionnement à long terme d'un laser CO_2 à guide d'ondes scellé"
par P. Pace et J. Cruickshank

Nous avons utilisé un spectrographe de masse pour étudier la composition gazeuse lors du fonctionnement d'un laser CO_2 à guide d'ondes BeO. Les résultats de cette étude nous ont permis de construire des lasers à guide d'ondes scellés d'une durée utile supérieure à 7000 h. (NC)

CRDV R-4207/81 (NON CLASSIFIE)

Bureau - Recherche et Développement, MDN, Canada.
CRDV, C.P. 8800, Courcelette, Qué. GOA 1RO

"Fonctionnement à long terme d'un laser CO_2 à guide d'ondes scellé"
par P. Pace et J. Cruickshank

Nous avons utilisé un spectrographe de masse pour étudier la composition gazeuse lors du fonctionnement d'un laser CO_2 à guide d'ondes BeO. Les résultats de cette étude nous ont permis de construire des lasers à guide d'ondes scellés d'une durée utile supérieure à 7000 h. (NC)

CRDV R-4207/81 (NON CLASSIFIE)

Bureau - Recherche et Développement, MDN, Canada.
CRDV, C.P. 8800, Courcelette, Qué. GOA 1RO

"Fonctionnement à long terme d'un laser CO_2 à guide d'ondes scellé"
par P. Pace et J. Cruickshank

Nous avons utilisé un spectrographe de masse pour étudier la composition gazeuse lors du fonctionnement d'un laser CO_2 à guide d'ondes BeO. Les résultats de cette étude nous ont permis de construire des lasers à guide d'ondes scellés d'une durée utile supérieure à 7000 h. (NC)

END

DATE
FILMED
10-81

DTIC